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Simultaneous cultivation and pre-harvesting of microalgae in a lab-scale membrane photobioreactor (MPBR)

M.R. Bilad*, V. Discart, D. Vandamme, I. Foubert, K. Muylaert, I.F.J. Vankelecom

KU Leuven, Belgium

Microalgal biomasses have long been produced in rather small amounts in industrial-scale for high value markets, such as for animal and aquaculture feeds, nutraceutical products, pigments, and food supplements. For decades, extensive research has been performed to utilize microalgae to treat wastewaters and to use biomass building blocks as feedstock to produce biofuel, i.e. biomass as feed of anaerobic process to produce biogas, celluloses fraction as raw materials for bioethanol productions, and lipid fraction for biodiesel production. For these purposes, the amount of biomass needed is huge and the production costs should fall below 400 $/ton to be economically feasible, which is very far from current reported full-scale production costs. The costs depicted from a recently reported medium-scale plant showed that the production costs of microalgal biomass is still 173 times higher than the targeted value [1]. Therefore, to substantially reduce the production costs, significant improvements should be applied by optimizing many different aspects of the production process.

One of the inherent limitations to achieve high production rates of biomass is the washout problem. In a common photobioreactor, due to the relatively slow microalgal growth rate and the inability to decouple microalgal retention time (MRT) from hydraulic retention time (HRT), the biomass productivity can only be controlled by tuning the dilution rate (D). To manage this problem, application of a membrane photobioreactor (MPBR) for simultaneous production and pre-harvesting of microalgae is evaluated in this study. Coupling membrane filtration with a photobioreactor offers similar advantages as in a membrane bioreactor (MBR) for wastewater treatment. The MPBR was constructed by coupling the existing PBR with lab-made, flat-sheet polyvinylidene fluoride based microfiltration systems. The detailed description of the PBR is given elsewhere [2]. The filtrations were conducted at separated container allowing for up-concentration step and partial recycling of retentate into the PBR. Zhen-Feng et al. [3] could not prove the advantages of an MPBR for microalgal biomass production due to the abundance of multivalent cations in the feed which induced flocculation. Therefore, a more defined feed was used in this study.

The expected behavior of MPBRs were first simulated using growth kinetic data and were later validated in a lab-scale MPBR, cultivating freshwater microalgae *Chlorella vulgaris*. At the first stage, *Chlorella vurgaris*. was cultured in Wright's cryptophytes (WC) medium in a continuous PBR with different D values. After reaching steady state, dose-response tests were performed by additionally dosing concentrated nutrient separately into the PBR to find the limiting nutrient, as it is required for simulation. Afterwards, the maximum achieved biomass concentration by the set-up was obtained to ensure that the ranges of simulated parameters fell within the growth kinetic model conditions, i.e., keeping the growth under nutrient limitation and not under light limitation. In the second stage, the membrane was installed in the PBR and the set-up was run in an MPBR configuration. The operational parameters such as D, recycle ratio (R) and up-concentration factor (C) were varied, and the performance of the system was assessed.

Simulation results showed that MPBRs could be operated at much higher biomass concentrations, leading to much higher nutrient uptakes and higher biomass productivity. This

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result proves the advantages of using an MPBR and its potential to be implemented for microalgal biomass production. Apart from that, since the filtration tank is separated from the bioreactor, different R and C values could be applied, to give a wider degree of operational freedom. This stage would also act as a first step in an up-concentration process to reduce the microalgal biomass harvesting costs. For instance, maintaining the biomass concentration at a level of 0.6 g/L in the bioreactor and 10 times up-concentration in the filtration tank resulted in a 6 g/L microalgal broth concentration in the retentate. It means that 93% of the harvesting costs by means of other processes (i.e. centrifugation) to reach a final concentration of 20% w/v (typically obtained in the harvesting process) could be drastically reduced. In addition, the cost associated with membrane air bubble scouring can be eliminated by using an aerated stream from the PBR aeration. In the case of limited water resources, the permeate can be recycled and concentrated nutrients could be dosed after dilution with the recycled permeate.

The results from the PBR operation at different D values show the robustness of the set-up. Altering the applied D values was subsequently followed by the change in biomass concentration, according to the expected simulated behavior. Phosphorous was found to be the limiting substrate and the maximum applied biomass concentration was found to be higher than 1 g/L. Further increasing the biomass concentration would risk carbon and/or light limitation. The continuous tests on the performance of the MPBR with different D, R and C values are being conducted. In the upcoming tests, the nutrient uptake with respect to nitrogen and phosphate removal will be closely monitored. In addition, the performance of the membrane filtration and a fouling autopsy will also be presented.

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